Age and weather related influences on growth and wood properties of young Norway spruce

Modelling based on the
Bio4Energy Feedstock Spuce Trait Database

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The results presented will become part of an article authored by
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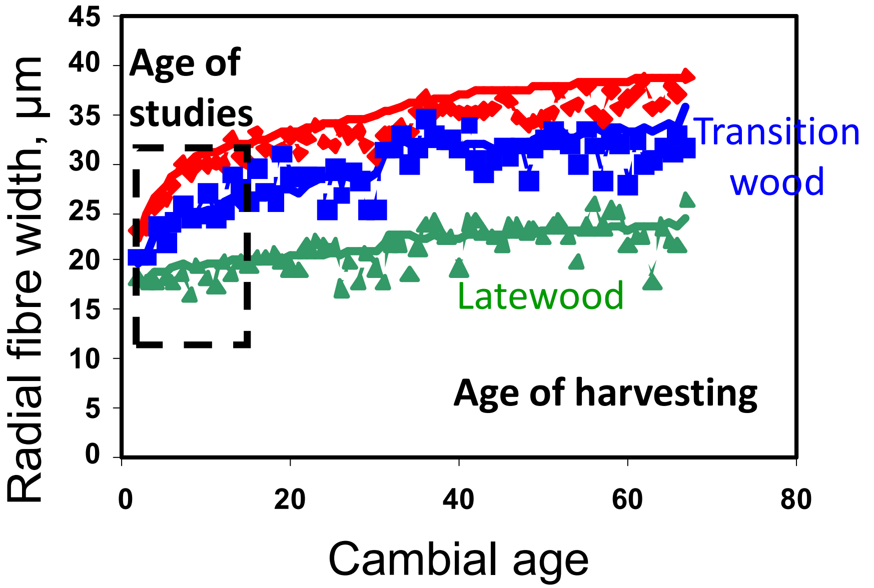
Introduction

Most research on tree genetics is performed on very young trees compared to harvesting age.

This is a dynamic phase of the trees' life, with rapidly changing intensities of processes in wood formation, reflected in growth and properties of wood and fibres. Still, few studies are done on these dynamics and how they are influenced by enviromental factors.



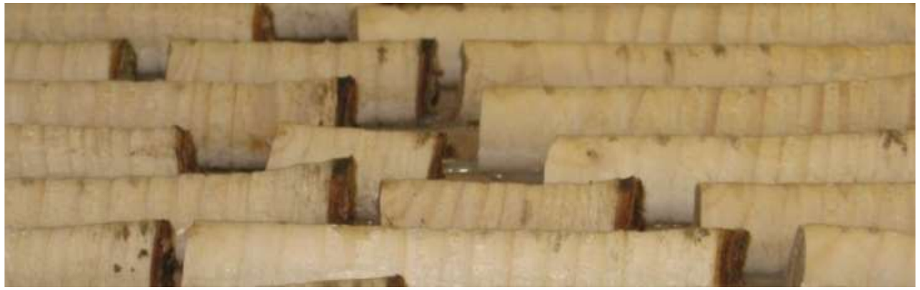
Objectives

1. To improve the knowledge on these dynamics and how they are influenced by weather/climate, and to formulate these influences on growth and properties in models
2. Start with processes of wood formation (cell division, expansion, biomass allocation), closely related to the genes, and go to traits of economic importance (growth, fibres, wood properties)
3. Develop methods for refinement of trait data from variations related to weather and age prior to genetic evaluations, in order to sharpen the results.
4. Ambition also to define traits reflecting how different genotypes respond to weather/climate, and to simulate scenarios of climate change

Materials and data

Samples collected by the Bio4Energy Feedstock platform

- Increment cores representing 524 families,
  6 trees of each family from 2 experiments, 1146 Höreda and 1147 Erikstorp,
  planted 1990, sampled at age 21 years, totally about 6000 trees

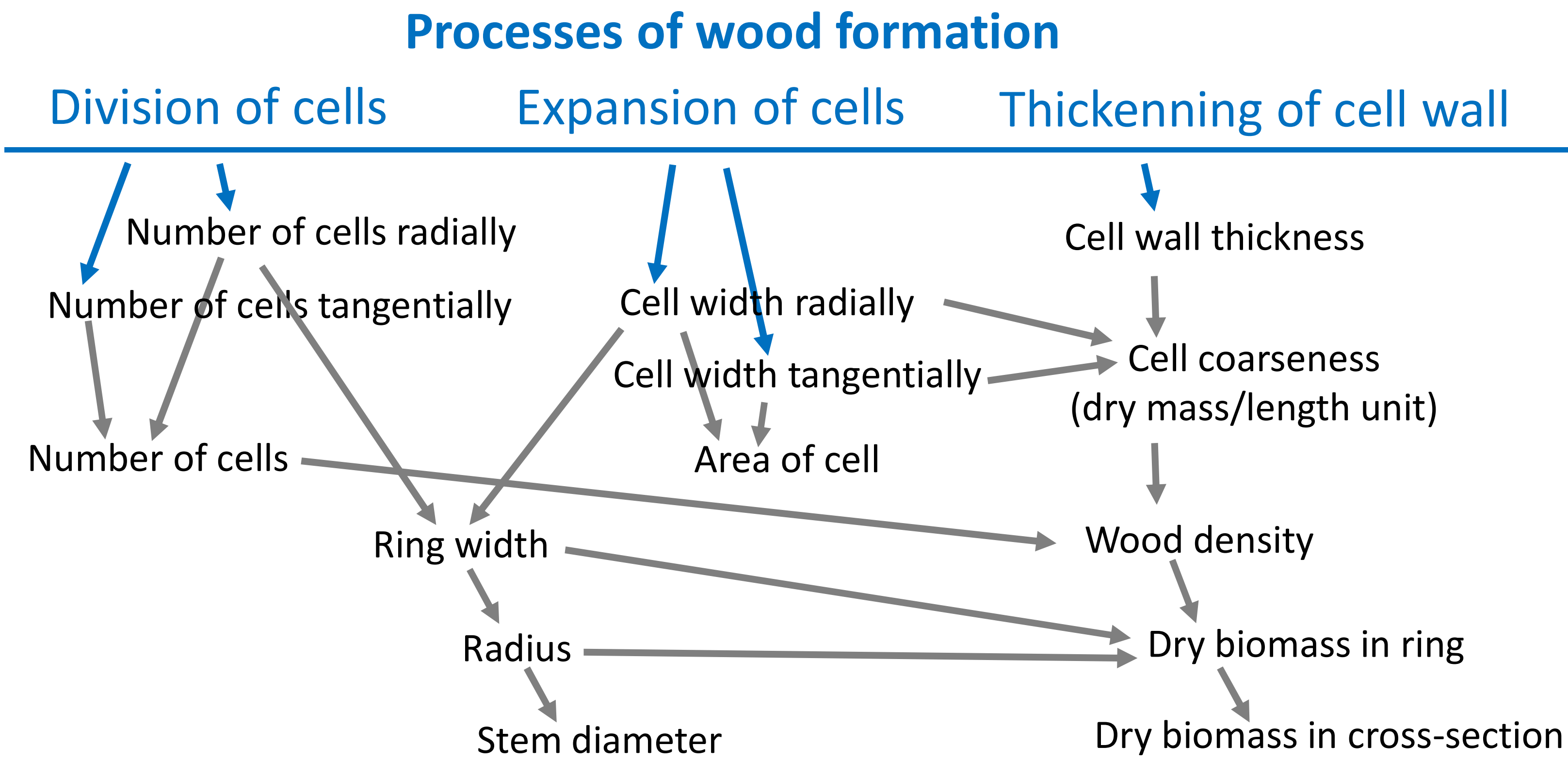


Data from the Bio4Energy Feedstock Spruce Trait Database

- SilviScan data on growth, wood and fibre properties refined for information on annual rings and their parts of earlywood, transitionwood and latewood, as well as traits like cell division per year
- Tree and site data from Skogforsk
- … complemented with meterological data for the sites from SMHI

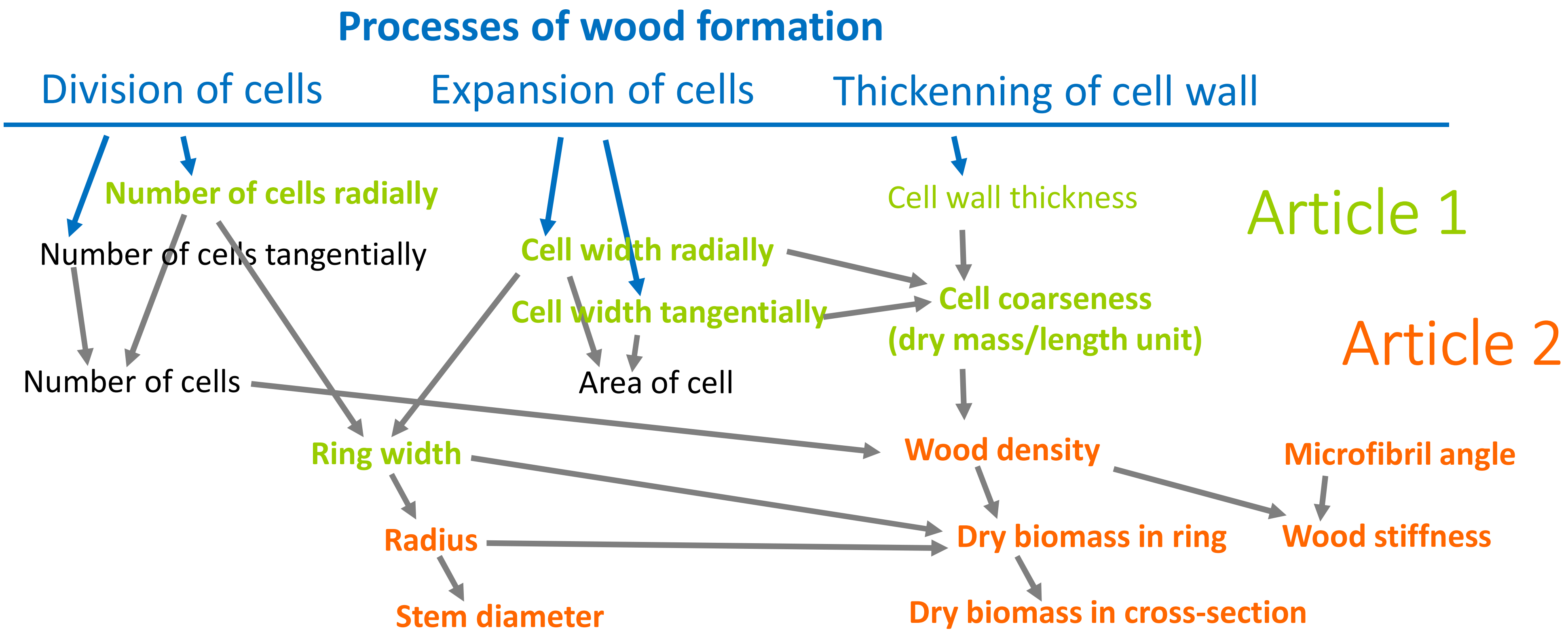
Processes of wood formation

and how they influence growth and properties



Processes of wood formation

and how they influence growth and properties



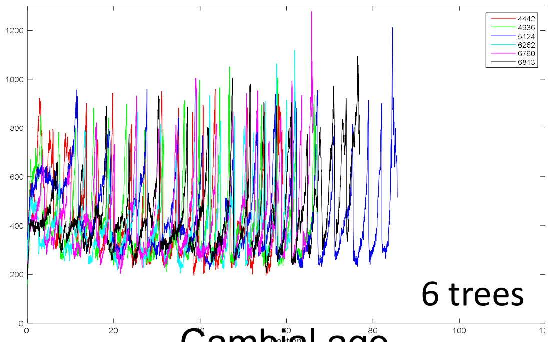
Example of within and between family variations

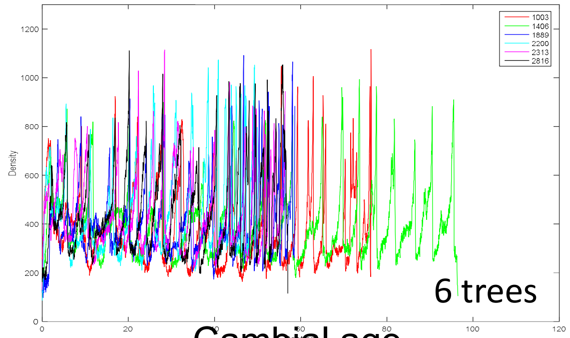
Wood density from pith to bark, radial growth and stem diameter

Site 1146

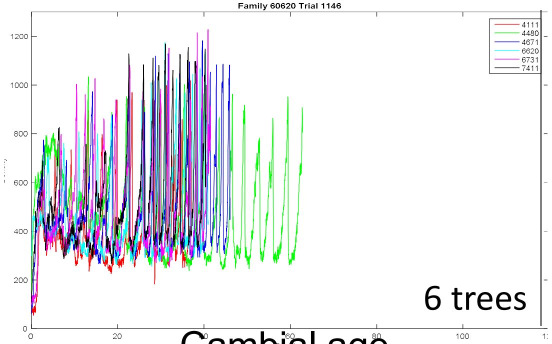
Site 1147

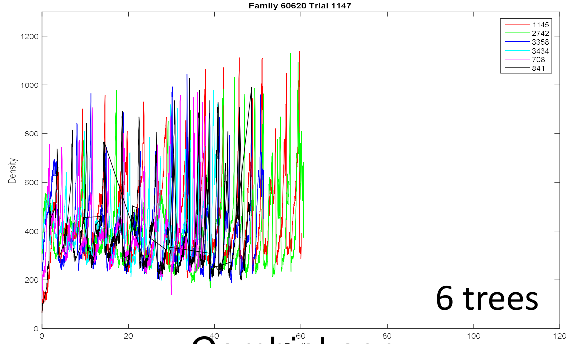
Fast-growning family



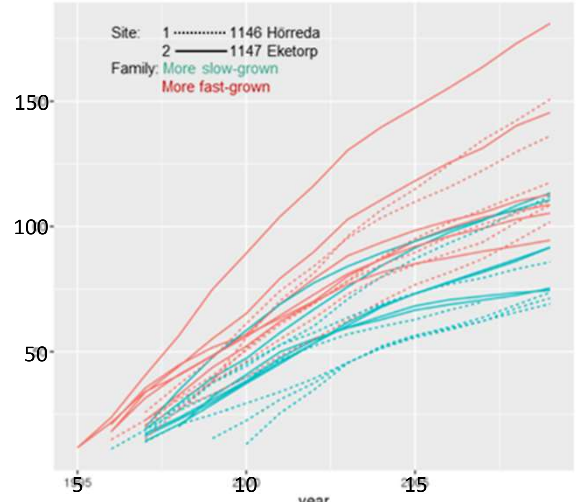


Slow-growning family





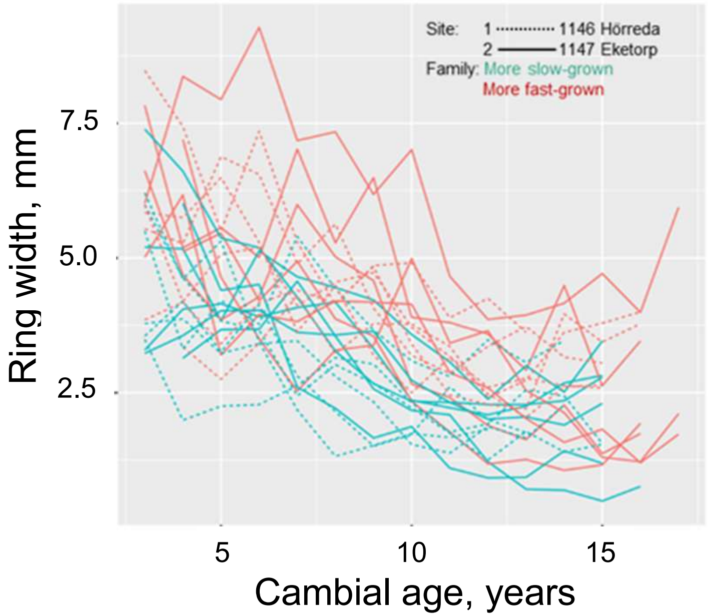
Stem diameter at breast height



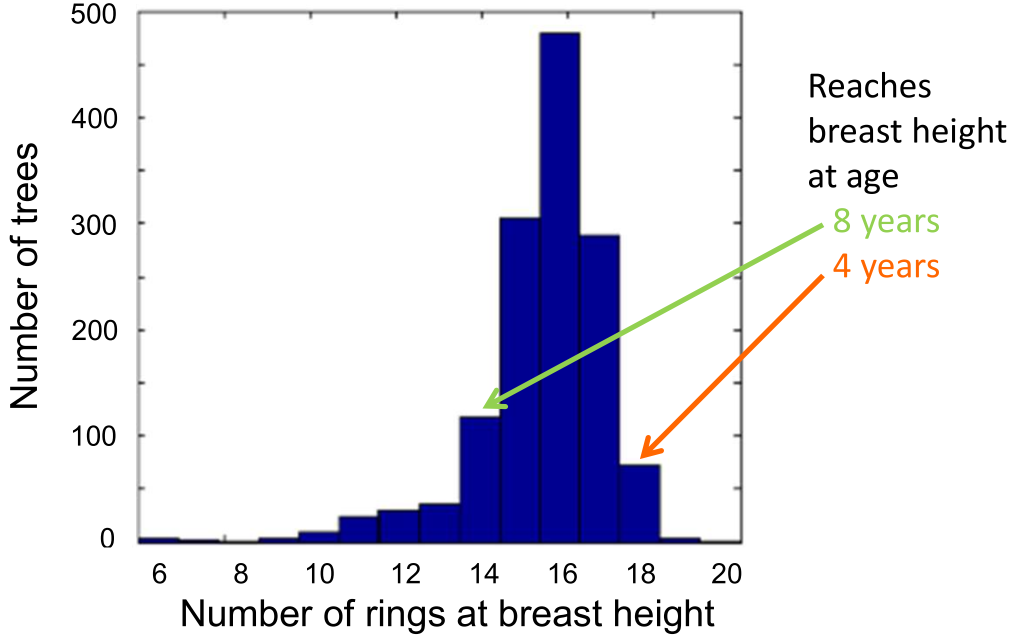
Large differences in growth within and between families

Underlying structures of variation

Ring widths versus cambial age
for the 24 trees



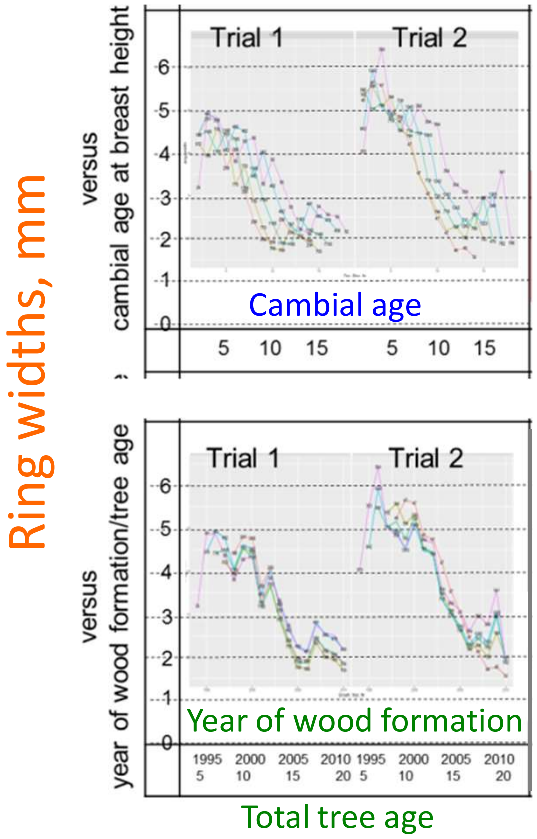
Number of rings at breast height
reflecting the age when the tree reaches BH

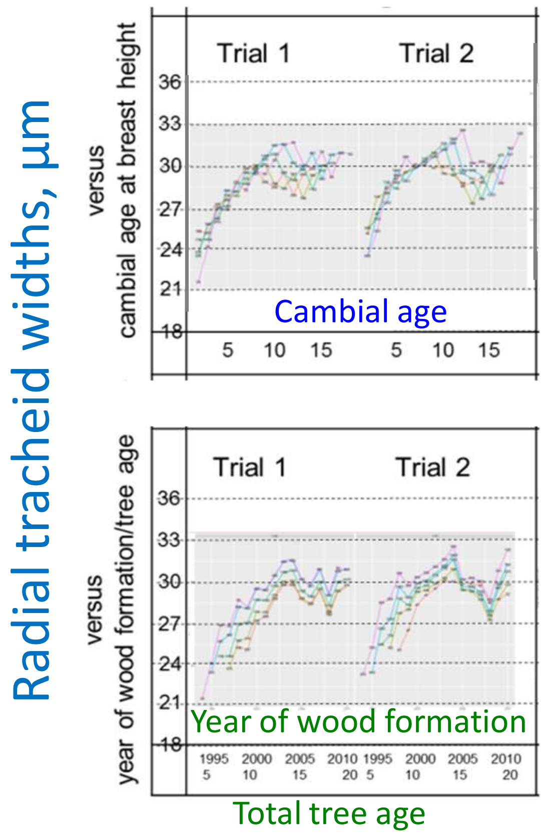


To reveal underlying structures, the trees were sorted into **classes of ages when reaching breast height**.
Average developments with age were calculated for each class.
The averages were plotted versus cambial age (traditional) and total tree age

Ring widths and radial tracheid widths

versus cambial age and total tree age

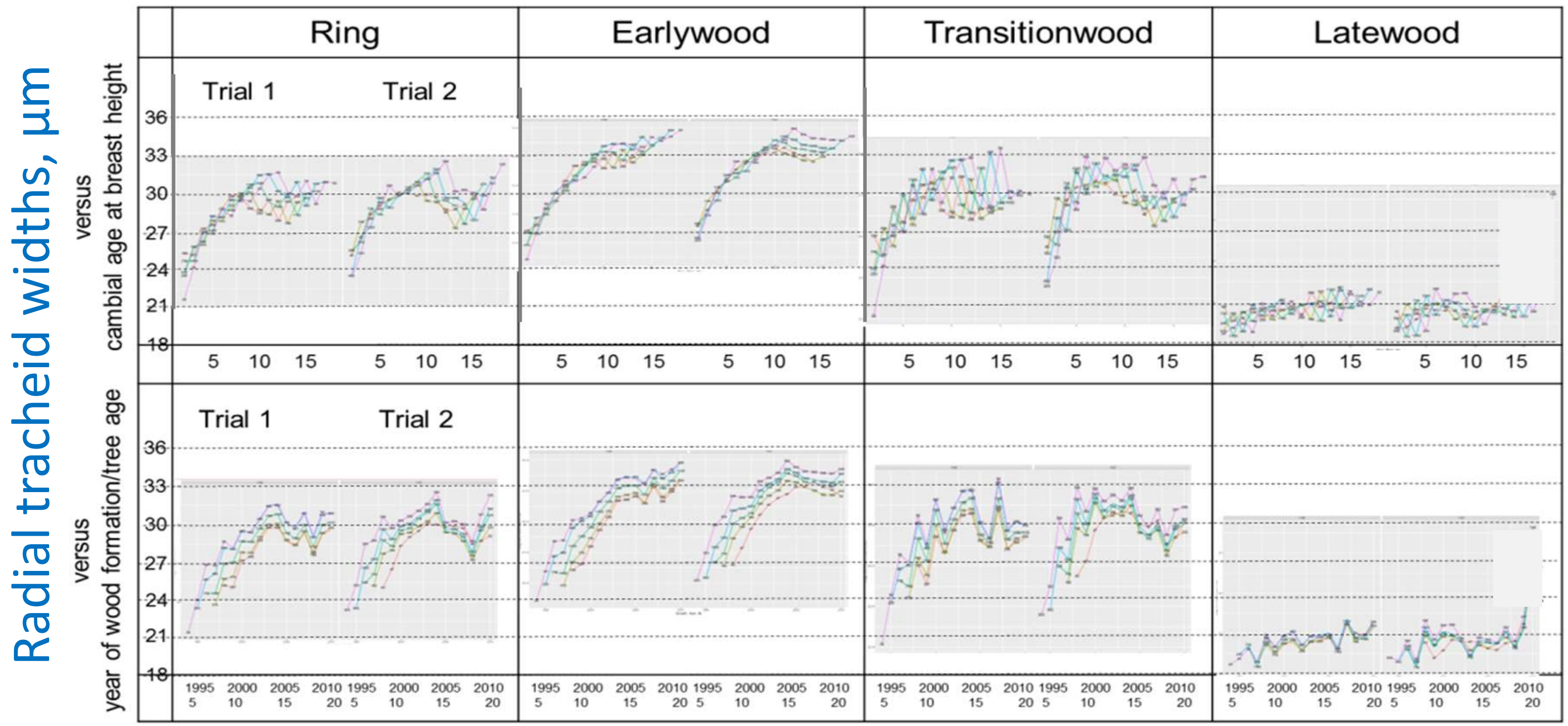




This indicates that for ring width, tree age is the stronger determinant

for radial tracheid width, cambial age is the stronger determinant

Radial tracheid width in rings and their parts



Largest weather effects in transitionwood

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Model structures

Many combinations and expressions of independent variables were tested,
in order to arrive at a limited number of input variables,
avoiding interdependent and covarying inputs.

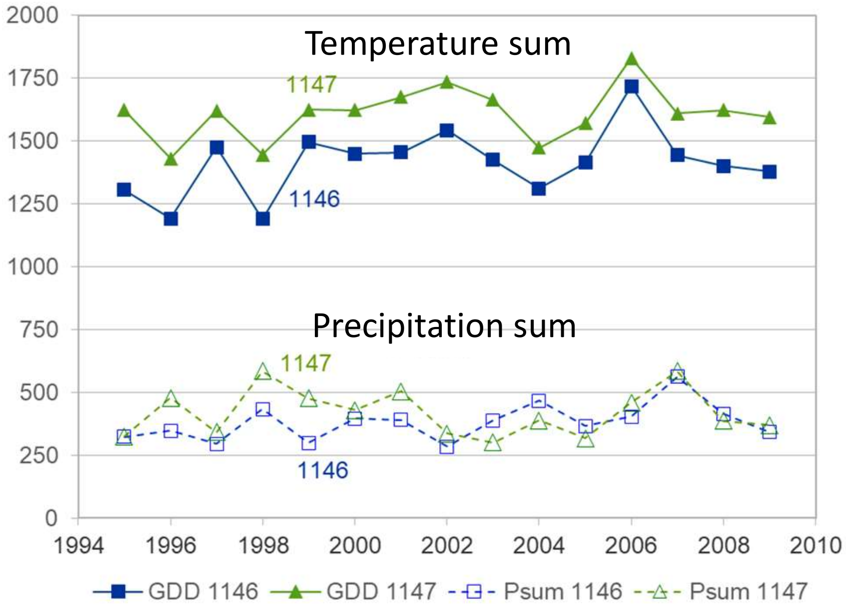
We also excluded independent variables expressing competition,
as their use may absorb information on genetic influences from the data.

Selected independent/fixed effect variables:

1. Age, two alternatives:
   a) Cambial age
   b) Total tree age
2. Temperature sum across the vegetation period of each year
3. Precipitation sums for equal length quarters of this vegetation period

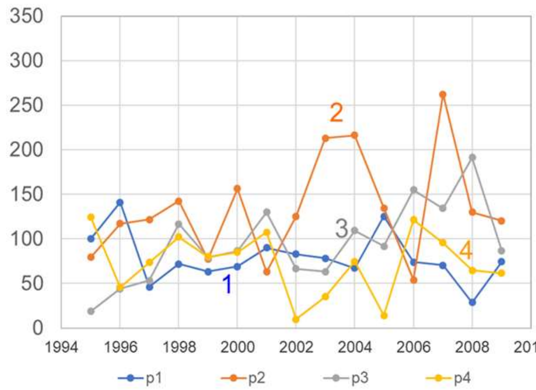
Sites and weather/climate

Temperature and precipitation sums across the annual vegetation periods



Precipitation sums for quarters of the annual vegetation periods

1146



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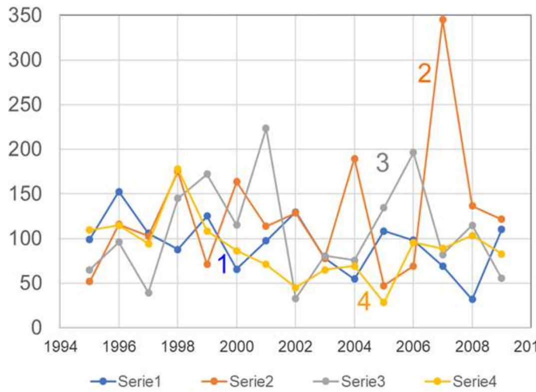


Statistical modelling

Generalised additive mixed model (GAMM) with cubic regression spline functions and an AR1 autoregressive element in the random part, hierarchical random part with tree (*i*) within family (*j*)

$$y_{ji} = \beta_0 + f_1(age_{ji}) + f_2(GDD_{ji}) +$$
$$f_3(precipQ1_{ji}) + f_4(precipQ2_{ji}) +$$
$$f_5(precipQ3_{ji}) + f_6(precipQ4_{ji}) + b_j + b_{ji} + \varepsilon_{ji}$$

where the ε_{ji} are zero mean normal random variables, with correlation given by

$$\rho(\varepsilon_{ji}, \varepsilon_{jk}) = \phi^{|age_{ji} - age_{jk}|}$$

age	> intrinsic
GDD	> extrinsic
precipQ	> extrinsic

Statistical modelling

Age part:
- Cambial age (CA)
- Total tree age (TA)

one at a time = 2 models

Generalised additive mixed model (GAMM) with cubic regression spline functions and an AR1 autoregressive element in the random part, hierarchical random part with tree (*i*) within family (*j*)

$$y_{ji} = \beta_0 + f_1(age_{ji}) + f_2(GDD_{ji}) + f_3(precipQ1_{ji}) + f_4(precipQ2_{ji}) + f_5(precipQ3_{ji}) + f_6(precipQ4_{ji}) + b_j + b_{ji} + \varepsilon_{ji}$$

Weather part:
- Temperature sum (T)
- Precipitation sums (P)

where the ε_{ji} are zero mean normal random variables, with correlation given by

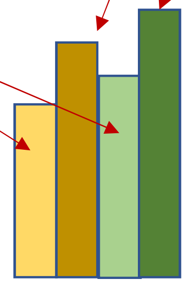
$$\rho(\varepsilon_{ji}, \varepsilon_{jk}) = \phi^{|age_{ji} - age_{jk}|}$$

age	> intrinsic
GDD	> extrinsic
precipQ	> extrinsic

Models compared:

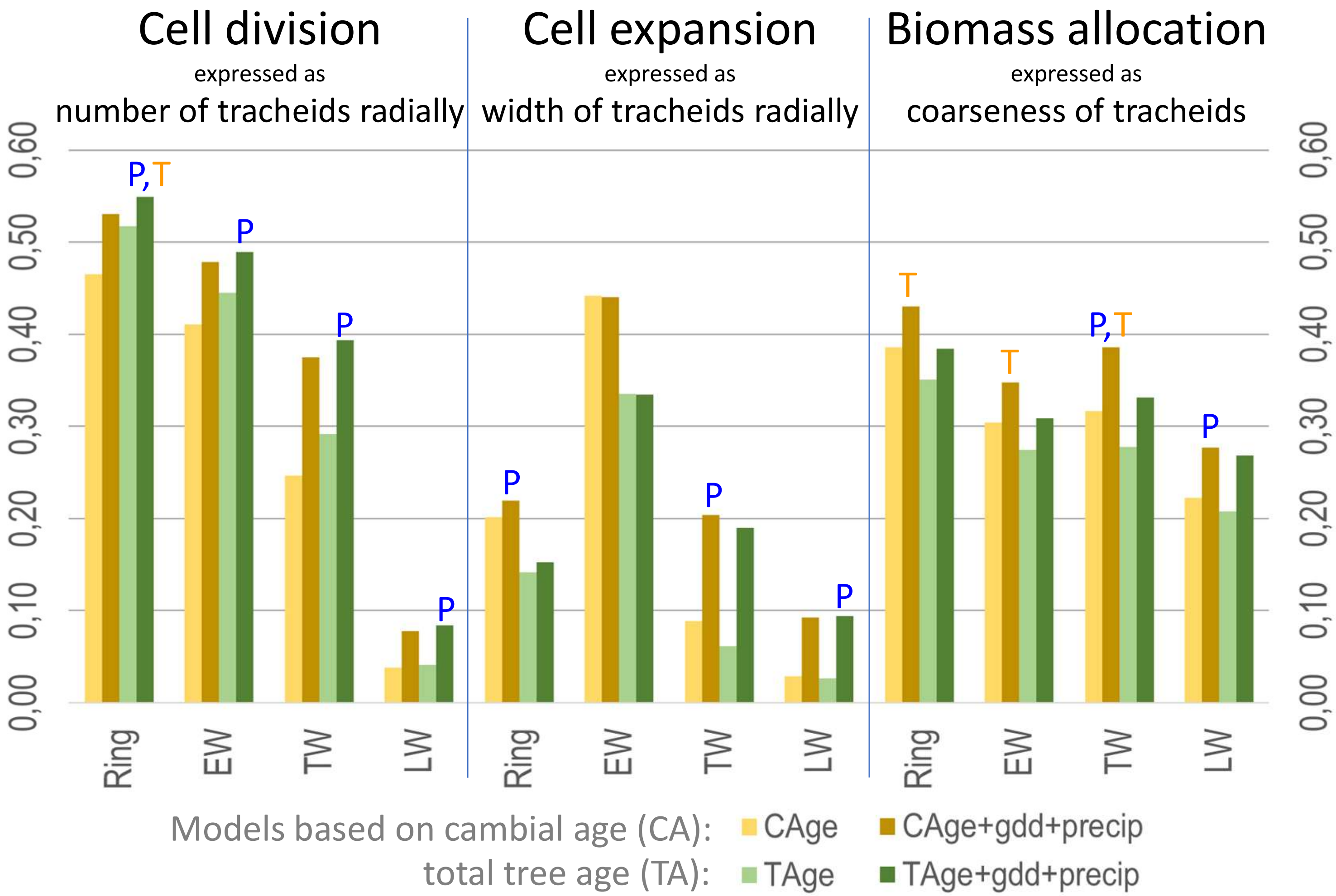
Age+weather

Age only



CA TA

R^2 values for models with different fixed effect variables



Weather-related effect dominated by:
T = temperature sum
P = precipitation sums

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R^2 values for models with different fixed effect variables

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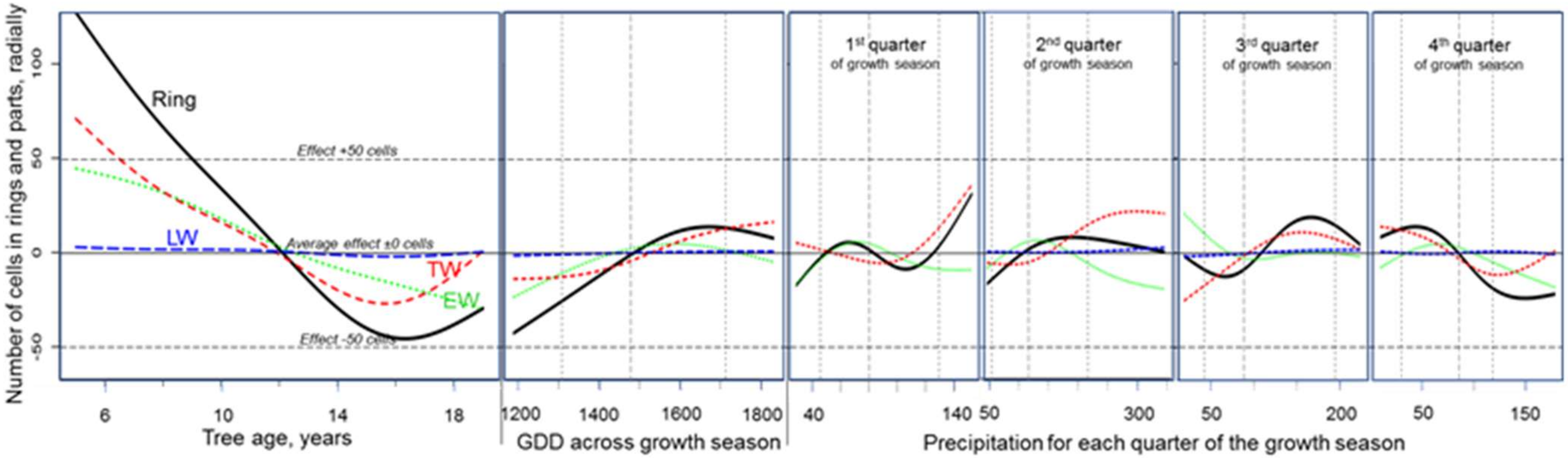
Models for number of tracheids radially

Averages in rings and their parts of earlywood, transitionwood and latewood



Baseline values

- Ring 3.41 mm
- EW 1.87 mm
- TW 1.29 mm
- LW 0.23 mm

Influences

on

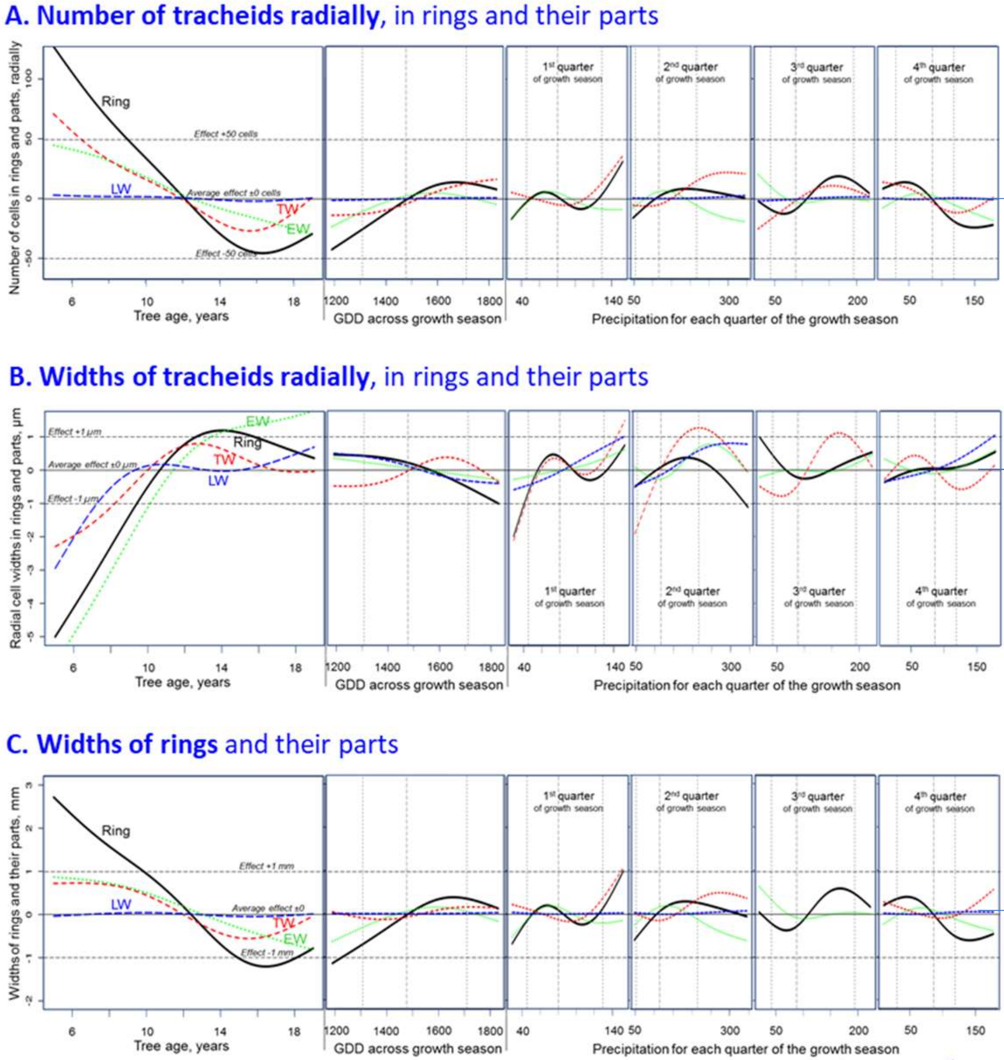
> cell divisions

> cell expansions

> ring widths

according to the models

Age expressed with
total tree age



Total total tree age

Temperature sum
across vegetation periods

1st 2nd 3rd 4th
Precipitation sums
across quaters of vegetation periods

Baseline values

- Ring 119.0
- EW 60.2
- TW 47.2
- LW 11.2

Baseline values

- Ring 29.1 µm
- EW 31.6 µm
- TW 27.4 µm
- LW 20.4 µm

Baseline values

- Ring 3.41 mm
- EW 1.87 mm
- TW 1.29 mm
- LW 0.26 mm

Influences

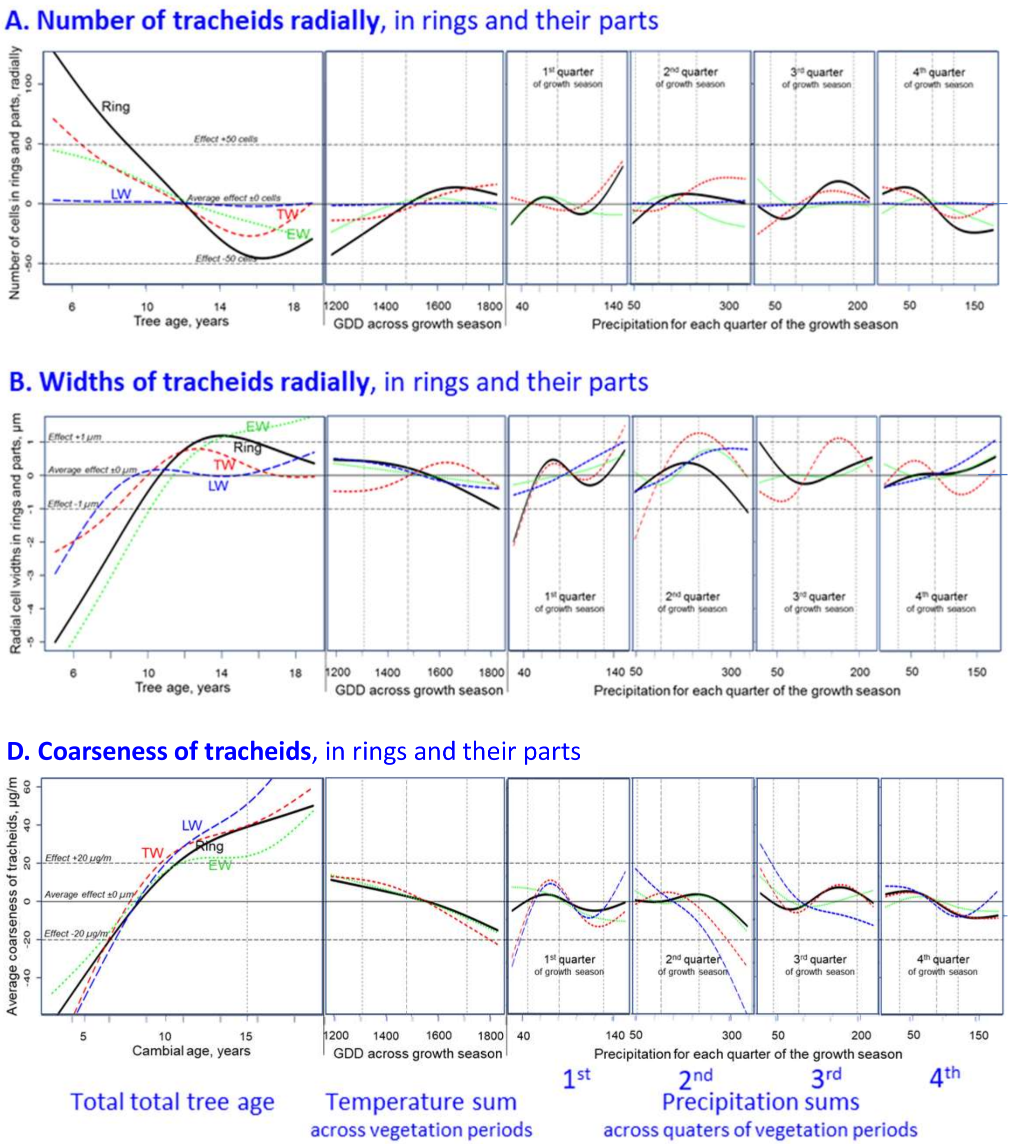
on

> cell divisions

> cell expansions

> cell coarseness

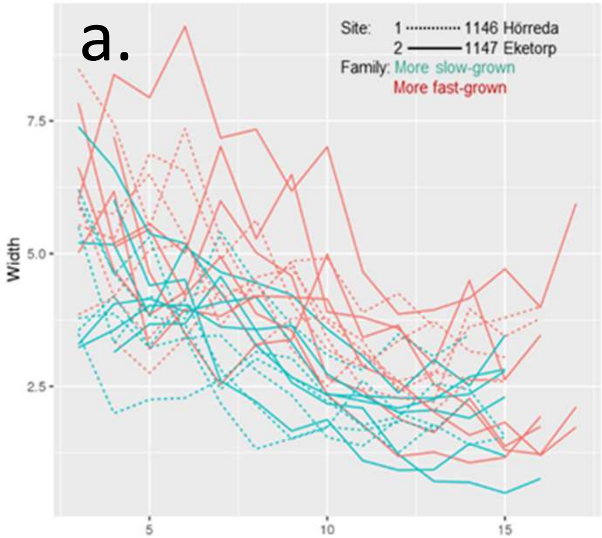
according to the models



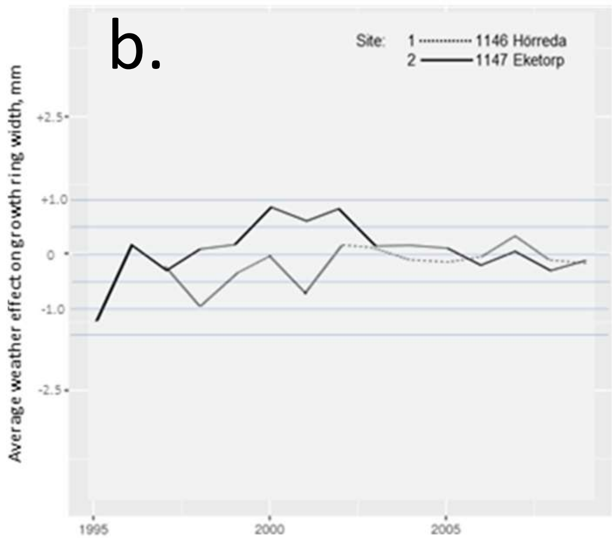
Example of application of the models:

Harmonisation of differences in climate among sites

Ring widths studied versus cambial age, the most common approach

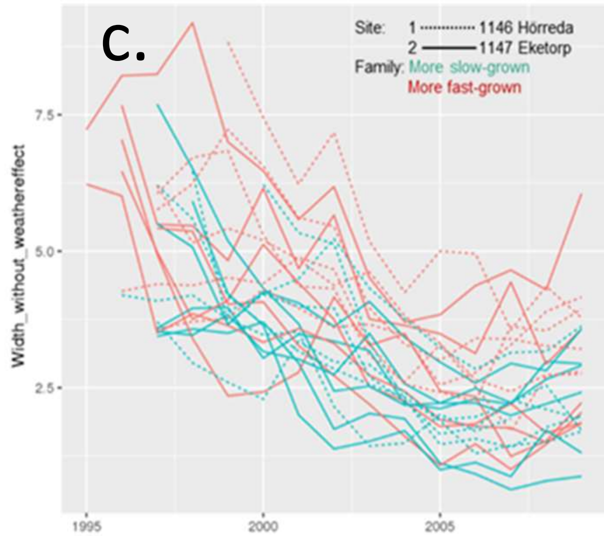


Estimated influences from weather for each year at the two sites



During 5 years, close to 1 mm broader rings at Eketorp due to weather differences

Ring widths compestated for estimated influences from weather per site and year



Ring widths ”as if average weather at both sites every year”

Conclusions and possibilities

- Age is the largest single source behind variations in growth, wood and fibre properties, together with effects from within stand competition
  - The intensity of radial cell division is under stronger control from total tree age than cambial age, and as a consequence also annual ring width
  - The adverse is valid for cross-sectional cell dimensions
  - The age-related control of other traits differ, and depends on interrelationships among traits
- Influences of variations in temperature and precipitation stands for a moderate but significant part of the variations in growth and properties

- By estimating weather and age related parts of growth and trait variations, it should be possible to
  - Make growth and property data from trees grown on sites with different weather more comparable, and also among experiments with different ages
  - Reduce weather-related year-to-year variation for better expression of genetic information in data
  - Possibly also to estimate new traits expressing how genotypes perform at different weather conditions